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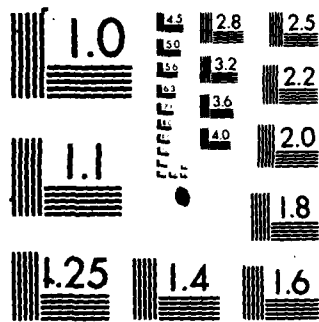
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AMMRC TR 82-19

DAMPING CHARACTERISTICS OF METAL MATRIX COMPOSITES

April 1982

NANCY S. TIMMERMAN
Bolt Beranek and Newman Inc.
10 Moulton Street
Cambridge, Massachusetts 02118

FINAL REPORT

Contract No. DAAG46-81-C-0036

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Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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ABSTRACT

→ Nine metal matrix composite materials were tested over the frequency range 4 to 10,000 Hz, at room temperature, to determine their damping properties. Cantilever beam samples were measured using both a logarithmic decrement test and a resonant dwell test to cover the entire frequency range. At a peak stress of 5 ksi, measured loss factors ranged from about 3×10^{-4} to 4×10^{-3} , with the graphite/aluminum composites generally showing the best (highest) performance (loss factor). These values are measurably no greater than those obtainable on the unreinforced matrix alloys.

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FOREWARD

This is the Final Report on BBN Job Number 08499, "Damping Characteristics of Metal Matrix Composites," prepared by BBN for the Army Materials and Mechanics Research Center (AMMRC) under Contract Number DAAG-46-81-C-0036. The work described in this report was conducted in the period 1 March 1981 through 19 January 1982. Mr. John Nunes was the Technical Monitor for AMMRC. The BBN personnel who contributed to this program include Drs. E. Ungar and J. Heine, Messrs. M. Fitzgerald and J. Doherty; and Ms. N. Timmerman.

Respectfully submitted,
BOLT BERANEK AND NEWMAN INC.

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Senior Vice President

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ABSTRACT

DAMPING CHARACTERISTICS OF METAL MATRIX COMPOSITES

Nine metal matrix composite materials were tested over the frequency range 4 to 10,000 Hz, at room temperature, to determine their damping properties. Cantilever beam samples were measured using both a logarithmic decrement test and a resonant dwell test to cover the entire frequency range. At a peak stress of 5 ksi, measured loss factors ranged from about 3×10^{-4} to 4×10^{-3} , with the Graphite/Aluminum composites generally showing the best (highest) performance (loss factor). These values are measurably no greater than those obtainable on the unreinforced matrix alloys.

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1. INTRODUCTION

In the present study, nine metal matrix composite materials were tested over the frequency range 4 to 10,000 Hz, at room temperature, to determine their damping properties (Ref. 1). It is understood that the objective of this initial study is to determine the relative merit of the nine materials with respect to their damping characteristics.

Because of this large frequency range, and the specification of sample type (cantilever beam), a combination of measurement techniques was used, each appropriate over part of the range. From 30 to 1000 Hz, a technique for determining the damping at a peak stress, called the resonant dwell technique (Ref. 2), was used. Above 1000 Hz and below 30 Hz, a logarithmic decrement method, using higher order modes and tip masses, respectively, was employed. The two tests lead to equivalent results if the specimen loss factors are high ($\eta > 10^{-2}$). Then, extraneous losses associated with the logarithmic decrement technique can be ignored. If loss factors are low, air damping may dominate. This program was based on the assumption that air damping was insignificant.

The following sections discuss the test specimen materials and configuration, the test methods used, and the results obtained. Problems encountered, and the significance of data obtained are also discussed, along with recommendations for future work.

2. DISCUSSION

2.1 Test Specimens

Test specimens of the nine different metal matrix composite materials covered by this study were procured, in accordance with the RFP (Ref. 1). The procurement was divided between two vendors: DWA Composite Specialties, Inc., and duPont Textile Fibers Department. DuPont supplied all FP fiber composites, while DWA supplied all the others.

The nine metal matrix composite materials were:

1. Graphite/Aluminum: The graphite fibers were of pitch precursor type, with a modulus of 55 Msi. The aluminum alloy was 6061.

2. Graphite/Aluminum: The graphite fibers were of pitch precursor type, with a modulus of 100 Msi. The aluminum alloy was 6061.

3. Graphite/Magnesium: The graphite fibers were of pitch precursor type, with a modulus of 55 Msi. The magnesium alloy was ZE41A.

4. Graphite/Magnesium: The graphite fibers were of the pitch precursor type, with a modulus of 100 Msi. The magnesium alloy was ZE41A.

5. FP/Aluminum: FP was Al_2O_3 fiber. The aluminum alloy was aluminum with 2% lithium.

6. FP/Magnesium: FP was Al_2O_3 fiber. The magnesium matrix was ZE41A.

7. FP/Magnesium: FP was Al_2O_3 fiber. The magnesium matrix was commercially pure magnesium.

8. SiC/Aluminum: The silicon carbide was in particulate form with a volume fraction of 45%. The aluminum alloy was 6061.

9. SiC/Aluminum: The silicon carbide was in whisker form with a volume fraction of 20%. The aluminum alloy was 6061.

Materials 1 through 7 contained continuous reinforcing fibers, oriented parallel to the longest dimension of the cantilever beam specimens, with a volume fraction of $50 \pm 5\%$.

Each material was represented by at least three identical cantilever beam specimens. The specimen dimensions are given in Fig. 1. For each material, there were three specimens with a beam length, L_s , of 6". For the six materials supplied by DWA an additional specimen, with beam length, L_s , of 12" was also obtained.

Representative values for the material density and Young's modulus (parallel to the fiber direction for continuous fibers) were obtained from the materials supplier for each of the nine composites. These values are given in Table 1. DuPont supplied a single value, while DWA provided an average value and tolerance for the Young's modulus for each material.

2.2 Test Methods

In order to span the frequency range, 4 to 10,000 Hz, with the specified samples, two different measurement techniques were used in three different frequency regions. Between 30 and 1000 Hz, a technique for determining the damping at a peak sample stress, called the resonant dwell technique (Ref. 2) was used. This range was determined from material properties and optical range limitations. At high frequencies, the resolution of the measuring microscope was 2.5 mils, effectively limiting us to 1000 Hz for a peak sample stress of 5000 psi. At low frequencies, we were limited to the fundamental frequency of the sample. Beam Modes 1 and 2 were measured using this technique.

Resonant frequencies below 30 Hz were obtained using a 12 in. sample in conjunction with tip masses. A logarithmic decrement test was used, since tip displacements were very large, with the sample mounted vertically to minimize the static stress due to the (up to 2#) tip mass.

To obtain frequencies up to 10,000 Hz, flexural modes through the fifth are required for these samples (see Appendix A). These modes can most easily be excited using a log decrement arrangement. Tip displacements here are very small, so displacements were measured using a proximity (displacement) probe.

Table 2 shows the actual configurations used to obtain the frequency range required for all specimens. The frequencies measured are also given. Details of the two measurement techniques are given below.

2.2.1 Resonant dwell test

The single cantilever beam resonance dwell apparatus is used to determine the stress and frequency dependence of material damping at engineering stress levels in the frequency range 30-1000 Hz.

The resonance dwell technique is a forced vibration method of indirectly determining the loss factors of simple structural elements by measuring their response to excitation at a modal frequency. For a thin beam, where the modes and dynamic stress distributions are well known, the specific damping capacity of the material (energy dissipated per unit volume in one stress cycle at a given peak stress divided by 2π times the peak potential energy in the unit volume at the same stress) may be inferred from the determined loss factor.

In this test, the specimen loss factor in a mode (usually the fundamental) is determined from the resonant amplification factor, or Q , of the specimen in that mode. The mechanical Q of a vibrating system is defined in terms of a characteristic deflection δ of the system due to distributed exciting forces proportional to the inertia forces of the mode in question. The amplification factor at resonance is

$$Q = \frac{\delta_{\text{res}}}{\delta_0}$$

where δ_0 is the deflection due to the distributed exciting force being applied statically and δ_{res} is the deflection when the same pattern of forces is applied in simple harmonic motion at the modal natural frequency. The relationship between Q , the specimen loss factor η , and the logarithmic decrement Δ of single-degree-of-freedom system is

$$\Delta = \frac{\pi}{Q} = \pi \eta .$$

The advantages of the resonance-dwell method are: first, the ratio $\delta_0/\delta_{\text{res}}$, for a properly designed specimen, is dependent only upon the damping in the specimen; second, the vibration amplitude δ_{res} may be maintained at any constant level so that

specimen damping may be determined as an *increasing* function of stress, eliminating the possibility of stress history effects; and third, because nothing is attached directly to the vibrating specimen, extraneous energy losses are minimized.

The method for ensuring that the beam specimen is excited at a mode is straightforward. The apparatus is constructed in such a way that the specimen acts as a vibration absorber placed on an excited single degree-of-freedom supporting system (see Fig. 2). At a natural frequency of the beam, the response of the supporting system is minimized. The frequency of the response minimum, and hence of the beam mode, can therefore be determined by monitoring the acceleration of the supporting system.

The experimental arrangement is shown in Fig. 3. A cantilever beam specimen of a test material is clamped to a bar (B) which is connected at one end to an electromagnetic shaker and the other to a heavy base. The thickness of the bar at the base end has been reduced by a saw cut to provide a pivot around which the remainder of the bar can rotate when excited by the shaker. The shaker is connected to the bar by a rod which passes through a hole in the base.

In this experiment, the resonant dwell test was used at a constant peak stress of 5000 psi. For this case, the double amplitude of the specimen tip displacement, $y_{t,DA}$, is pre-determined (see Appendix A). As a result, the shaker excitation was adjusted for a tip displacement corresponding to the desired peak sample stress.

The response of the supporting system [$y(t)$ in Fig. (2)] to shaker excitation is measured with an accelerometer mounted on the bar at the root of the specimen. The double amplitude of the specimen tip displacement ($x(t)$ in Fig. (2)) is measured optically with a low power microscope with a retical. The specimen loss factor is then calculated from the measured root acceleration as follows:

$$\eta = 0.083 (1+0.2L) \frac{a_0}{f_n^2} \frac{1}{y_{t,DA}}$$

where η is the specimen loss factor, f_n is the natural frequency, $y_{t,DA}$ is the double amplitude tip displacement, a_0 is the root acceleration, and L is the specimen length

2.2.2 Logarithmic decrement test

In the logarithmic decrement method, used above 1000 Hz and below 30 Hz, the specimen was excited electromagnetically and beam response was measured with a displacement (proximity) probe and

arrangement used in the logarithmic decrement test was the same as was that used in the resonant dwell apparatus, but the sample was affixed to the base instead of to the hinged support.

In the logarithmic decrement method, the beam is excited at a resonant frequency, and the rate of decay of response of the beam is measured following cessation of the excitation. The loss factor is:

$$\eta = - \frac{\ln\left(\frac{a_f}{a_i}\right)}{\pi f T},$$

where f is the frequency (Hz), a_f is the final amplitude, a_i is the initial amplitude, and T is time to decay (sec). Because of the changing displacements as the beam response decays, this method is stress-varying, and results are valid if the loss factor is not stress-dependent in the range of stresses present during the test.

Two different configurations were used for the different frequency ranges. At low frequencies (below 30 Hz), a tip mass was attached to the beam and excited. Decay of the fundamental, as seen by the proximity probe, was recorded on a strip chart recorder. For the higher modes (above 1000 Hz), displacement was measured by the proximity probe, but decay was recorded on a long-persistence scope, with a scope camera. A log converter was used to give a linear decay, enabling direct reading of the loss factor.

2.3 Results

The computed loss factors for the nine metal matrix composite materials, at the frequencies measured, are summarized in Table 3. Frequencies between 30 and 1000 Hz were measured with the resonant dwell technique. All other results are from logarithmic decrement tests. Sample fundamentals, between 100 and 250 Hz were measured with both methods.

All tests were run at 5000 psi peak sample stress or less (in the case of log decrement). All resonant dwell tests were done at approximately 5000 psi peak sample stress. Where possible (at low frequencies), the log decrement test was run with the initial stress level at 5000 psi. At higher frequencies, this was not possible. As a result, to a certain extent, the results may show stress dependence.

Not all measurements yielded reliable values for loss factor. At the highest frequencies, a spurious signal was often generated by the switch, which both signalled the scope to trigger, and turned off the electromagnetic drive. In some cases, only one or two cycles would be displayed before the contamination was visible. In these cases, loss factor was not computed, since the data were not considered reliable. In one additional case, no measurement was made because of difficulties in attaching the tip mass to material 8.

In general, the graphite composites showed higher loss factor than the FP or SiC composites. In the overlap region, logarithmic decrement and resonant dwell results agreed fairly well. The values for loss factor were fairly constant over the frequency range measured, with the average being slightly higher for the aluminum matrix than for the magnesium matrix.

The FP composites had the next highest loss factors. These materials were very uniform from sample to sample, unlike the graphite composites, where sample-to-sample differences were large. In the overlap region results did not agree, with the smaller value being as small as $1/3$ of the larger. The reasons for this discrepancy are not clear. The values of loss factor computed for the higher frequencies showed a larger scatter, due to the greater uncertainty inherent in the measurement procedure.

The SiC composites had the smallest values of loss factor. Sample-to-sample agreement was good, as was the comparison of the two methods in the overlap region. These materials appear to have a minimum value of loss factor, as a function of frequency. For the 45% particulate composite, this minimum η of about .0004 occurred around 2000 Hz, while for the 20% whisker composite, the minimum of about .0003 occurred around 3500 Hz.

It is probable that the values reported here include other forms of damping besides material damping. In all cases, air damping is expected to be significant at the lowest frequencies (Ref. 2), where the displacements are large. At higher frequencies, the air damping is small. Extraneous sources of damping in the logarithmic decrement method may also be important for this range of loss factors.

Experimental error, due to sample-to-sample differences, was large. For the graphite composites, variations of up to $\pm 30\%$ were observed. Errors observed at a given frequency due to

sample-to-sample differences were generally about $\pm 10\%$ for the other composites. At the highest frequencies, resolution of the amplitude measured was the greatest source of error, and variations of $\pm 60\%$ were not at all uncommon. In general the two highest modes measured were affected by this uncertainty.

In terms of frequency averaged loss factors, the materials would be rank ordered, from highest to lowest:

- 1) 55 Msi Graphite/6061 Aluminum
- 2) 100 Msi Graphite/6061 Aluminum
- 3) 55 Msi Graphite/ZE41A Magnesium
- 4) 100 Msi Graphite/ZE41A Magnesium
- 5) FP/2% Li-Aluminum
- 6) FP/ZE41A Magnesium
- 7) 45% Part. SiC/6061 Aluminum
- 8) 20% Whisker SiC/6061 Aluminum
- 9) FP/C.P. Magnesium.

It should be noted that the graphite composites samples were prone to chipping, and the supplier had to refabricate due to problems with lamination.

2.4 Summary

Damping tests were run on nine different metal matrix materials. The samples were cantilever beams. A frequency range of 4 to 10,000 Hz was covered using a combination of resonant dwell and logarithmic decrement techniques. Tests were run at room temperature at a peak sample stress level of 5000 psi and less.

Computed loss factors ranged from 3×10^{-4} to 4×10^{-3} . These values are measurably no greater than those obtainable on the unreinforced matrix alloys. The graphite composites showed the highest loss factors, followed by FP composites, and SiC composites. Loss factor was roughly frequency independent for the graphite and FP composites. SiC composites exhibited a minimum in the loss factor-frequency plot. Sample-to-sample variations ranged from 10 to 30%. The damping effectiveness of the materials roughly decreased in the same order as the composite materials were originally numbered (with #1 (55 Msi Gr/Al) being best and #9 (20% SiC/Al) worst).

3. RECOMMENDATIONS

The results presented here represent the results of cantilever beam tests with fixed sample sizes over a fairly large (4-10,000 Hz) frequency range, at room temperature, as required by the RFP (Ref. 1). These tests are more suitable for the investigation of parameters other than frequency, since they are resonance tests. In particular, the resonant dwell technique is much better suited to investigation of stress dependence or temperature dependence. Other kinds of tests (Ref. 3) are more suited to investigations of frequency dependence.

We would recommend resonant dwell tests (~100-200 Hz) at higher stress levels and temperatures on all of the materials tested in this study, in order to characterize their damping properties more accurately.

For more accurate, more complete frequency dependent tests, we would recommend the use of a load frame device, where modulus and loss factor can be measured simultaneously (see Ref. 3).

REFERENCES

1. "Investigation of Damping Characteristics of Metal Matrix Composites," AMMRC, Solicitation No. DAAG 46-80-Q-0616, September, 1980.
2. "The Stress and Frequency Dependence of Material Damping in Some Engineering Alloys," J.C. Heine, Ph.D. Thesis, MIT, June 1966.
3. N.S. Timmerman, "Assessment of Dynamic Modulus Testing Facilities," BBN Tech Memo 652, February 1982.
4. Harris and Crede, *Handbook of Sound and Vibration*, Second Ed., McGraw-Hill Book Co., New York, 1976.

APPENDIX A. STANDARD BEAM EQUATIONS

The material frequencies of a cantilever beam of length L (in.) and thickness h (in.) are:

$$f_1 = \frac{1}{2\pi} \left(\frac{1.8751}{L} \right)^2 h \left(\frac{32E}{\rho} \right)^{\frac{1}{2}}$$

$$f_2 = 6.36f_1$$

$$f_3 = 17.53f_1$$

$$f_4 = 34.38f_1$$

$$f_5 = 56.82f_1$$

where

E = Young's modulus (psi) and

ρ = material density (lb_m/in^3) .

The tip amplitude as a function of specimen stress and material properties is given by:

$$y_{t,DA} = A_n \left(\frac{\sigma_\rho}{f_n} \right) \frac{1}{\sqrt{E\rho}}$$

where

$y_{t,DA}$ = peak-to-peak amplitude (in)

σ_ρ = maximum stress (psi)

f_n = specimen natural frequency (Hz), and

A_1 = 3.63

A_2 = 3.747

A_3 = 1.808

A_4 = 1.806

A_5 = 2.224

For the case where there is a tip mass, w , the fundamental natural frequency of the beam and mass becomes (Ref. 4):

$$f_n = \frac{1}{4\pi} \sqrt{\frac{bh^3 E g}{L^3 [w + 0.23 \rho b h L]}}$$

where

b = sample width (in)

g = gravitational constant.

TABLE 1. Composite Material Properties

Material	Vendor	Density (lb/in ³)	Young's Modulus (psix10 ⁶)
1. 55 Msi Graphite/ 6061 Aluminum	DWA Composite Specialties, Inc.	.085	26.43 \pm .95
2. 100 Msi Graphite/ 6061 Aluminum	"	.085	42.5 \pm 2.7
3. 55 Msi Graphite/ ZE41A Magnesium	"	.068	23.14 \pm .93
4. 100 Msi Graphite/ ZE41A Magnesium	"	.068	40.75 \pm .4
5. FP(Al ₂ O ₃)/ 2% Lithium- Aluminum	DuPont Textile Fibers Dept.	.1156	32
6. FP (Al ₂ O ₃)/ ZE41A Magnesium	"	.1048	30
7. FP (Al ₂ O ₃)/ Comm. Pure Magnesium	"	.1048	30
8. 45% Particulate SiC/ 6061 Aluminum	DWA Composite Specialties, Inc.	.104	21.95 \pm .71
9. 20% Whisker SiC/ 6061 Aluminum	"	.102	14.09 \pm .62

TABLE 2. Actual Test Configurations Used

	1	2	3	4	5	6	7	8	9
	55 Msi Gr 6061 Al	100 Msi Gr 6061 Al	55 Msi Gr ZEUJA Mg	100 Msi Gr ZEUJA Mg	FP-A1 ₂ O ₃ 25 Li-Al	FP-A1 ₂ O ₃ ZEUJA Mg	FP-A1 ₂ O ₃ C.P. Mg	45% Part. Sic 6061 Al	20% Mh. SIC 6061 Al
f	5.77	7.65	5.97	7.79	8.05	7.48-7.74	7.83-7.91	Not meas.	6.25
Test*	LD	LD	LD	LD	LD	LD	LD	LD	LD
Sample Size	12"	12"	12"	12"	6"	6"	6"	12"	12"
Mode	1	1	1	1	1	1	1	1	1
Tip Mass	1/2#	1/2#	1/2#	1/2#	2#	2#	2#	1/2#	1/4#
f	16.51	21.81	15.28	20.21	18.88	17.78-18.16	18.42-18.62	14.75-16.82	19.23-19.99
Test*	LD	LD	LD	LD	LD	LD	LD	LD	LD
Sample Size	6"	6"	6"	6"	6"	6"	6"	6"	6"
Mode	1	1	1	1	1	1	1	1	1
Tip Mass	1/2#	1/2#	1/2#	1/2#	1/2#	1/2#	1/2#	1/2#	1/4#
f	35.8	45.8	40.7	51.7	26.75	25.92-26.34	26.47-27.23	36.3	24.5
Test*	RD	RD	RD	RD	LD	LD	LD	RD	LD
Sample Size	12"	12"	12"	12"	6"	6"	6"	12"	12"
Mode	1	1	1	1	1	1	1	1	1
Tip Mass	0	0	0	0	1/4#	1/4#	1/4#	0	0
f	131-151	173-199	138-160.1	174-202.1	136-146.3	136-150.5	138-151.9	112-147.2	101-110.8
Test*	RD, LD	RD, LD	RD, LD	RD, LD	RD, LD	RD, LD	RD, LD	RD, LD	RD, LD
Sample Size	6"	6"	6"	6"	6"	6"	6"	6"	6"
Mode	1	1	1	1	1	1	1	1	1
f	837-919.3	291.9	965.2-981.1	320.6	915.6-918.7	923.2-943.8	940.7-952.5	780-899.3	686-694.9
Test*	RD, LD	RD	RD	RD	RD	RD	RD	RD	RD
Sample Size	6"	12"	6"	12"	6"	6"	6"	6"	6"
Mode	2	2	2	2	2	2	2	2	2
Frequency Range	1000 - 2500 Hz								
f	2385-2411	1112-1149	2545-2551	1126-1180	2479-2487	2470-2522	2506-2549	2069-2361	1832-1859
Test*	LD	LD	LD	LD	LD	LD	LD	LD	LD
Sample Size	6"	6"	6"	6"	6"	6"	6"	6"	6"
Mode	3	2	3	2	3	3	3	3	3
f	4665-4715	3157-3239	4965-4995	3186-3337	4872-4887	4856-4957	4930-5013	4075-4619	3614-3663
Test*	LD	LD	LD	LD	LD	LD	LD	LD	LD
Sample Size	6"	6"	6"	6"	6"	6"	6"	6"	6"
Mode	4	3	4	3	4	4	4	4	4
f	7604-7697	6159-6320	8168-8551	6212-6500	8029-8043	8000-8180	8130-8274	6760-7671	5977-6054
Test*	LD	LD	LD	LD	LD	LD	LD	LD	LD
Sample Size	6"	6"	6"	6"	6"	6"	6"	6"	6"
Mode	5	4	5	4	5	5	5	5	5

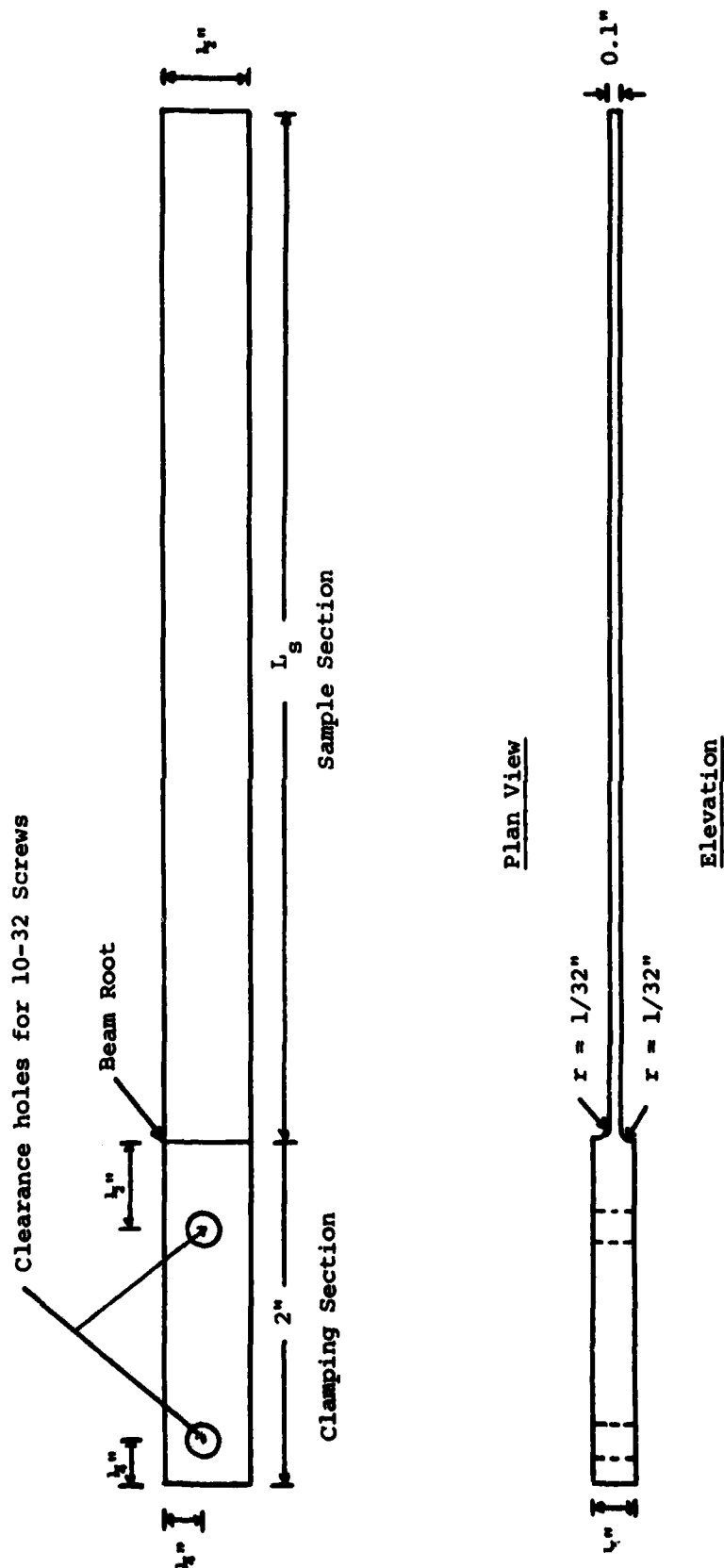
*LD = logarithmic decrement

RD = resonant dwell

TABLE 3. MEASURED RESULTS
Material

	1	2	3	4	5	6	7	8	9
	55 ksi Gr 6061 Al	100 ksi Gr 6061 Al	55 ksi Gr Z611A Mg	100 Gr Z611A Mg	FP-Al ₂ O ₃ 2% Li-Al	FP-Al ₂ O ₃ Z611A Mg	FP-Al ₂ O ₃ C.P. Mg	45% Part. SIC 6061 Al	20% Wh. SIC 6061 Al
f	5.77	7.65	5.97	7.79	8.05	7.48- 7.74	7.83- 7.91	Not	6.25
η	.00135	.00275	.00099	.00087	.00107	.00097- .00102	.00089- .00104	Meas.	.00148
f	16.51	21.81	15.28	20.21	18.88	17.78- 18.16	18.42- 18.62	14.75 17.45	19.23- 19.99
η	.00389	.00105	.00119	.00085	.00074	.00070- .00071	.00068- .00077	.00156- .00225	.00184- .00188
f	35.8	45.8	40.7	51.7	26.75	25.92- 26.34	26.47- 27.23	36.3	24.5
η	.00160	.00172	.00144	.00116	.00067	.00064- .00067	.00061- .00066	.00113	.00192- .00214
f	131- 151	173- 199	138- 160.1	174- 202.4	136- 146.4	136- 150.5	138- 151.9	112- 147.2	101- 110.8
η	.00158- .00276	.00118- .00262	.00108- .00203	.00081- .00225	.00045- .00165	.00050- .00150	.00044- .00126	.00053- .00118	.00075- .00129
f	837- 919.3	291.9	965.2- 981.1	320.6	915.6- 918.7	923.4- 943.8	940.7- 952.5	780- 899.3	686- 694.9
η	.00110- .00361	.00131	.00111- .00120	.00142	.00084- .00117	.00069- .00109	.00069- .00085	.00035- .00057	.00077- .00154
f	2385- 2411	1112- 1149	2545- 2551	1126- 1180	2479- 2487	2470- 2522	2506- 2549	2069- 2361	1832- 1859
η	.00154- .00190	.00137- .00290	.00111- .00175	.00124- .00209	.00142- .00153	.00085- .00154	.00063- .00127	.00038- .00111	.00027- .00034
f	4665- 4715	3157- 3239	4965- 4995	3186- 3337	4872- 4887	4856- 4957	4930- 5013	4075- 4619	3614- 3663
η	M.R.*	.00114- .00242	.00217- .00261	.00105- .00132	.00105- .00270	.00134- .00195	.00071- .00173	.00110- .00214	.00025- .00029
f	7604- 7697	6159- 6320	8618- 8551	6212- 6389	8029- 8043	8000- 8180	8130- 8274	6760- 7671	5977- 6054
η	M.R.*	.00134- .00224	.00106- .00223	.00106- .00107	.00106- .00175	.00102- .00262	.00105- .00267	.00038	.00053

*Not reliable.



Tolerances: Clamping Section - $\pm .02"$
 Sample Section - $\pm .005"$

FIGURE 1. METAL MATRIX COMPOSITE SAMPLE DIMENSIONS

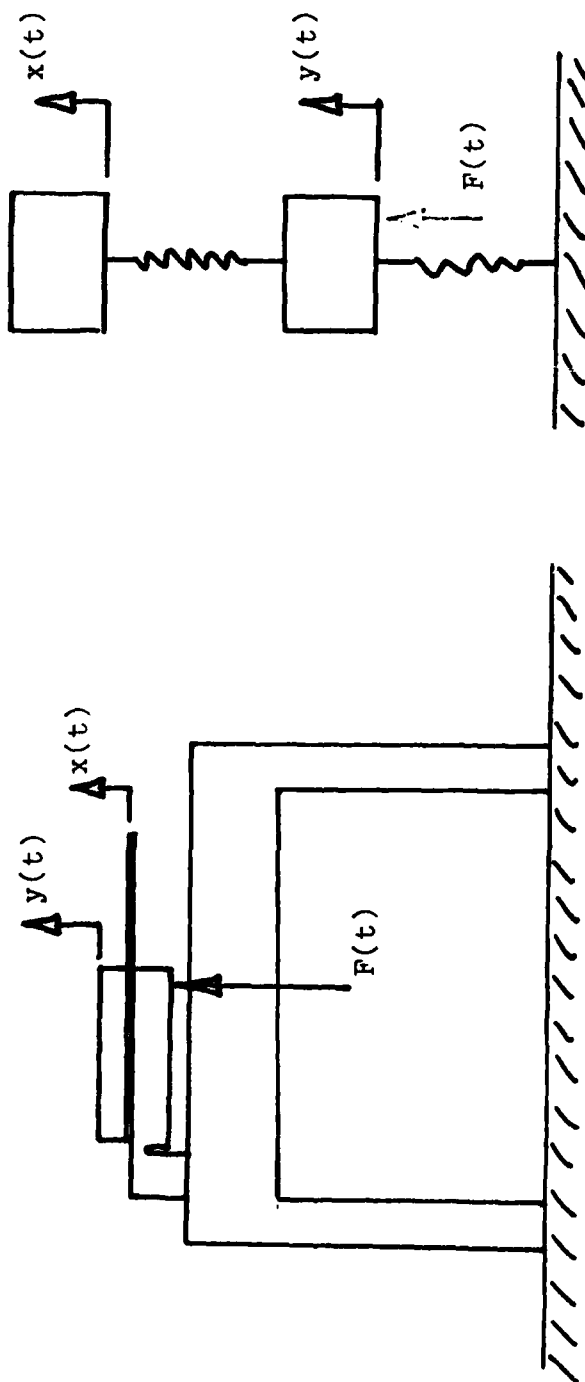


FIGURE 2

THE RESONANT DWELL DAMPING APPARATUS
 IS THE EQUIVALENT OF AN EXCITED SYSTEM
 WITH A RESONANT VIBRATION ABSORBER

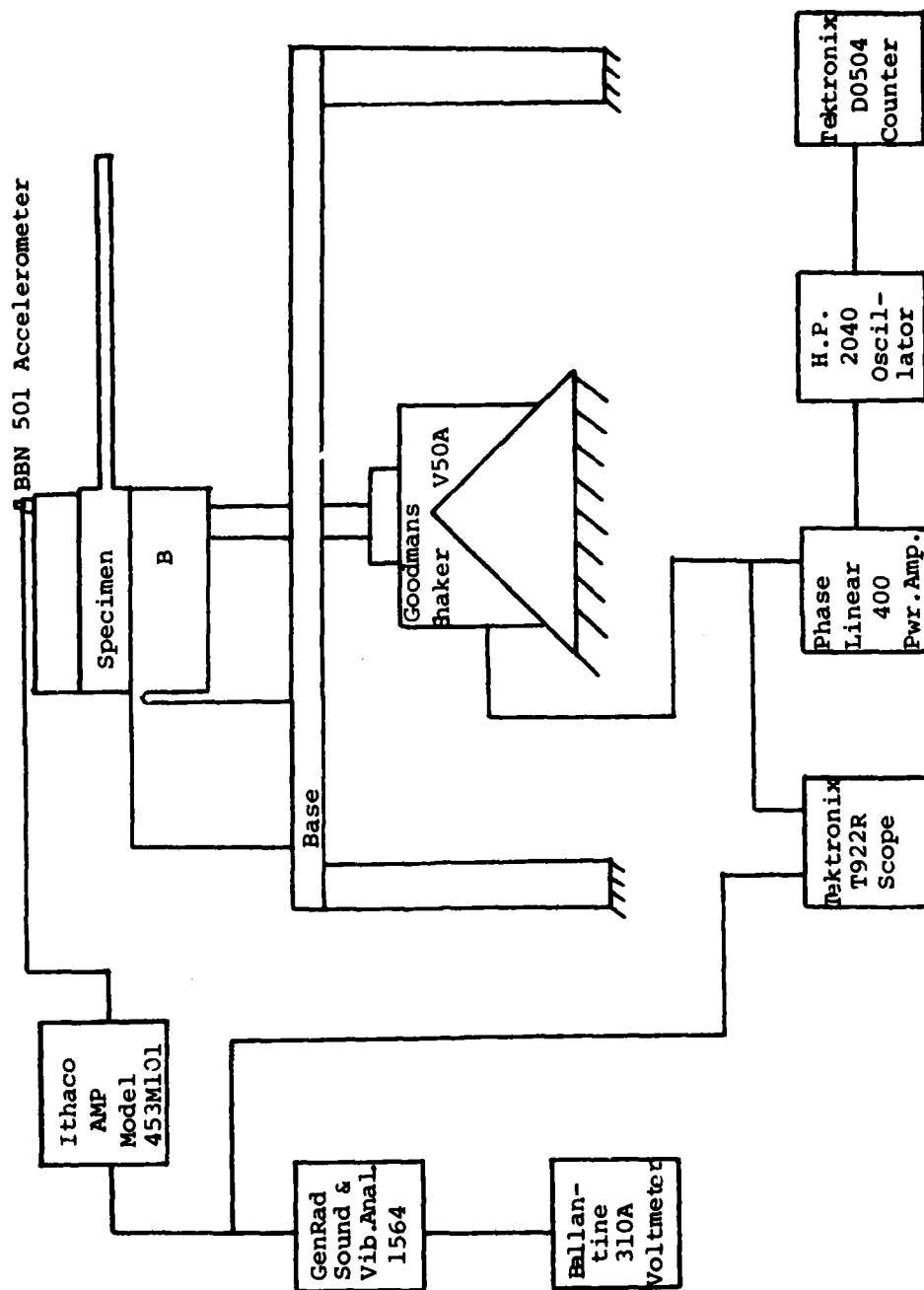


FIGURE 3. EXPERIMENTAL ARRANGEMENT FOR RESONANT DWELL TESTS

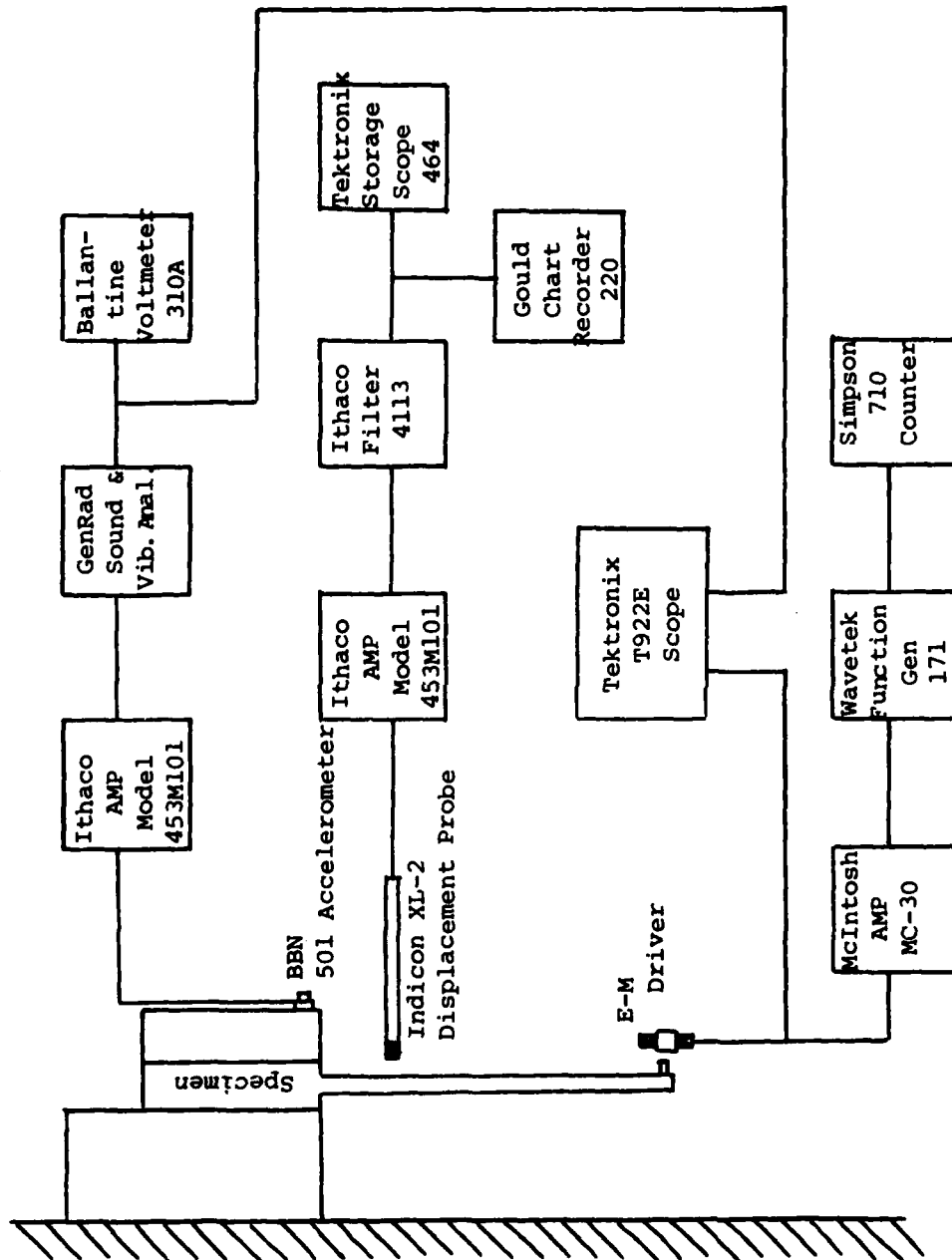


FIGURE 4. EXPERIMENTAL ARRANGEMENT FOR LOGARITHMIC DECREMENT TESTS

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Nancy S. Timmerman
Bolt Beranek and Newman Inc.
Technical Report AFWAC TR 82-19
April 1982, 25 pp.
illus - tables, Contract
No. DAAG46-81-C-0036

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